National Broadband Plan: Reaching the Goals
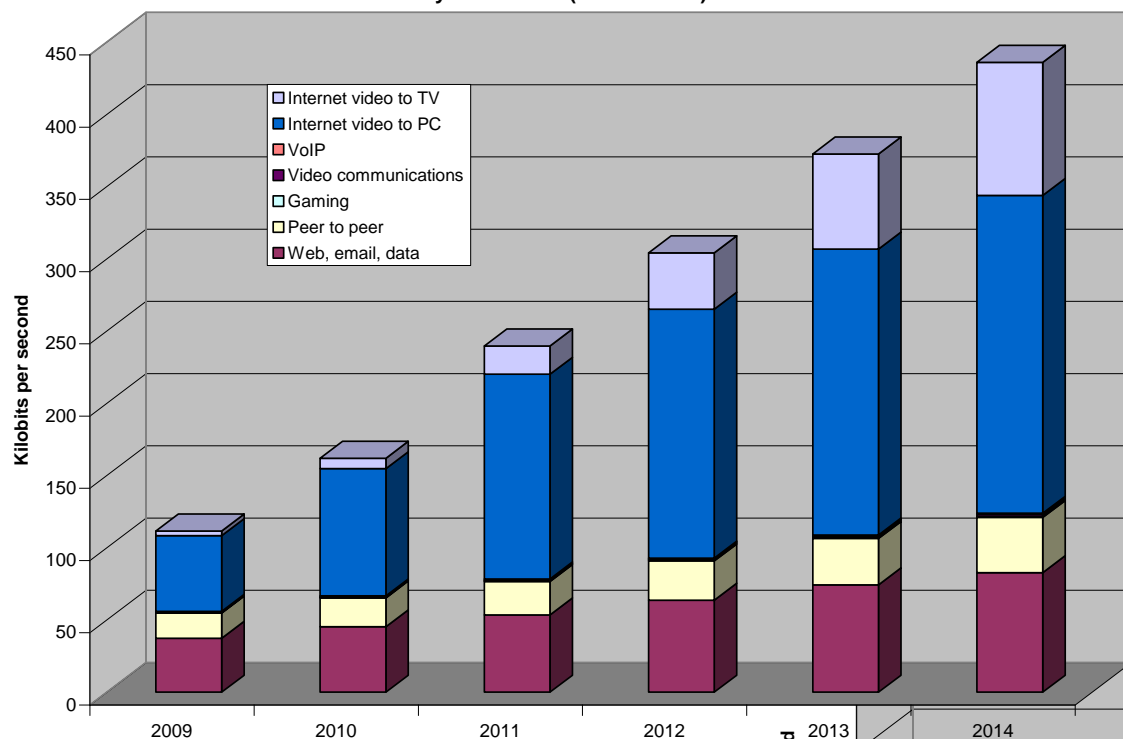
September 2010

Consumer Traffic Projections

- ## Cisco Visual Networking Index (VNI)
  - Estimates aggregate traffic for regions (e.g., North America)
  - Breaks down by application class (video, p2p, etc.)
  - Projections to year 2014

- ## ADTRAN per-household traffic projections
  - Cisco data used as baseline
    - Petabytes per month per continent
  - Converted to busy hour Mbps per household
  - Extended projections (as a range) to 2020

Busy hour traffic (downstream)

Legend:
- Internet video to TV
- Internet video to PC
- VoIP
- Video communications
- Gaming
- Peer to peer
- Web, email, data

Y-axis: Kilobits per second (0, 50, 100, 150, 200, 250, 300, 350, 400, 450)
X-axis: 2009, 2010, 2011, 2012, 2013, 2014

- **By 2014:**
  - OTT streaming video is 72% of total downstream traffic
  - Steady percentage decline in P2P

Busy hour traffic (upstream)

Y-axis: Kilobits per second (0, 10, 20, 30, 40, 50, 60)
X-axis: 2009, 2010, 2011, 2012, 2013, 2014
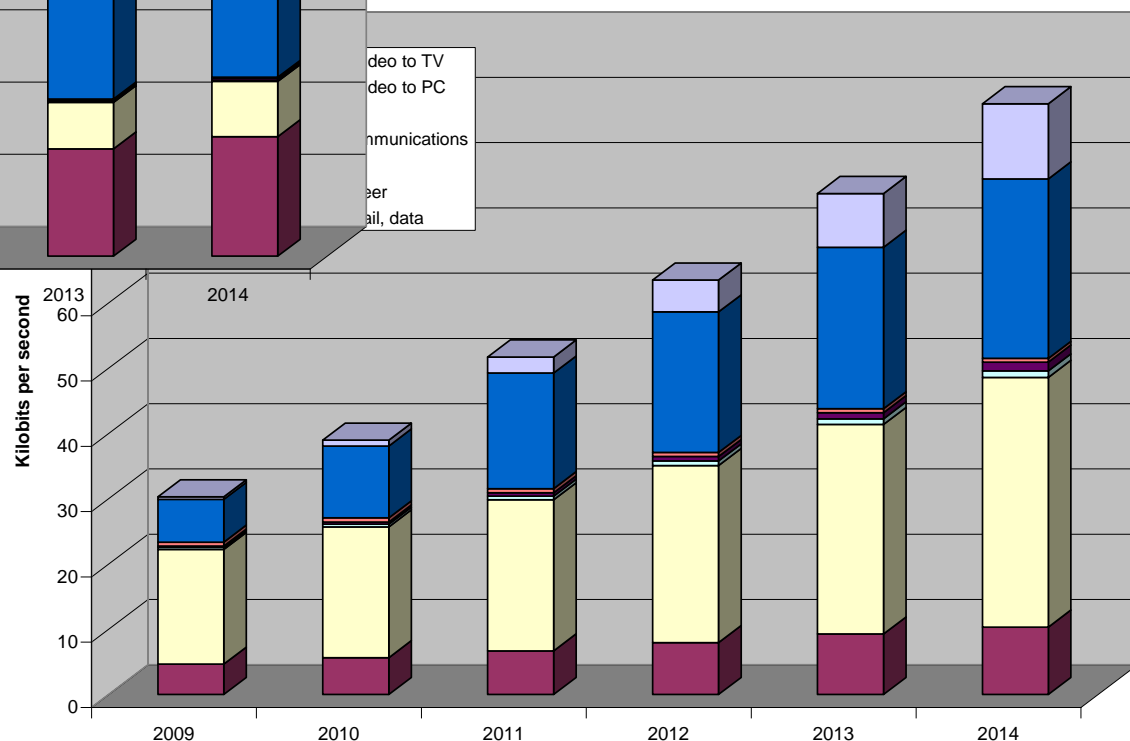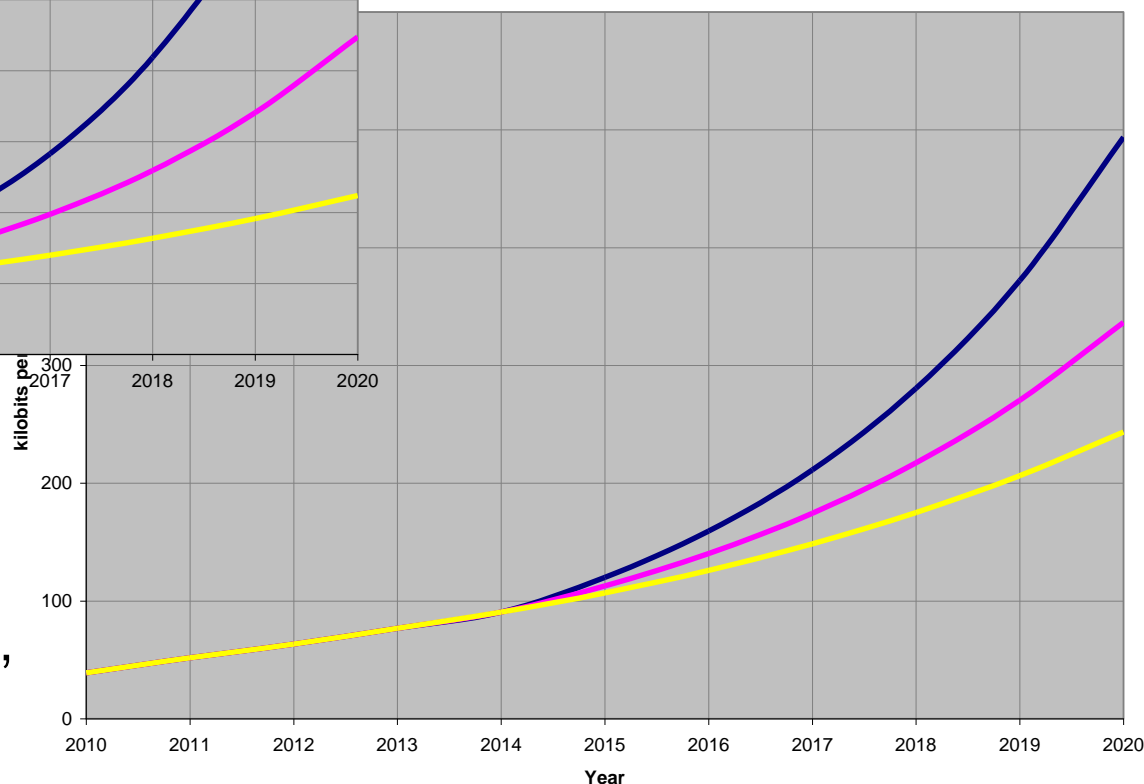
- **Consumer traffic is becoming more asymmetric**

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Busy hour traffic (downstream)

- Estimated range based on highest, lowest, and average CAGR for 2009-2014 in each direction
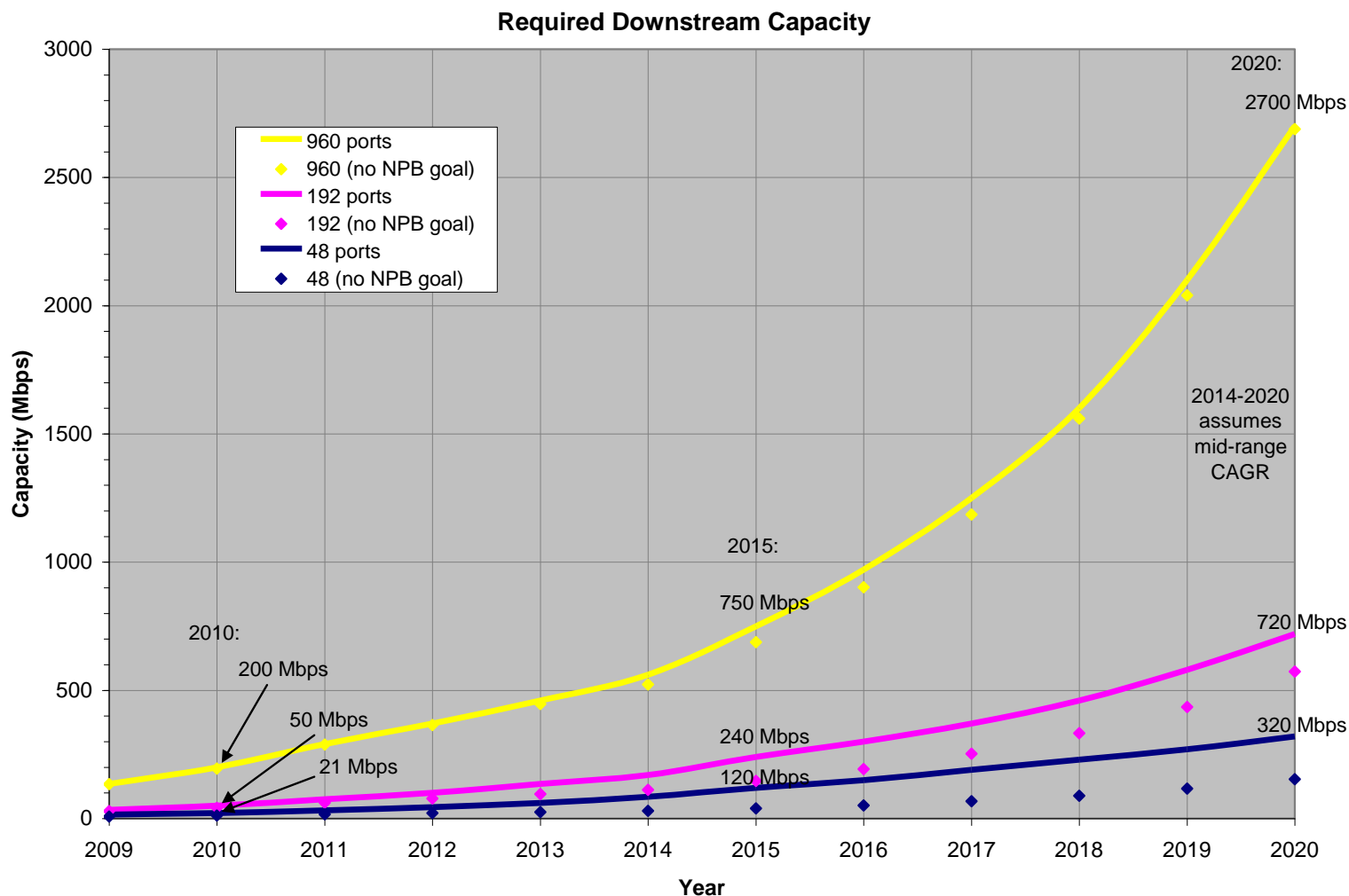
Busy hour traffic (upstream)

- 2015: 510 to 650 kbps down, 110 to 120 kbps up

- 2020: 1.1 to 4.6 Mbps down, 240 to 490 kbps up

5

National Broadband Plan

- Goal: "100 Mbps to 100 million homes by 2020"
  - 100 Mbps down, 50 Mbps up
  - Intermediate goal: 50 Mbps down, 20 Mbps up by 2015

- Minimum threshold for broadband: 4/1 Mbps

- "Actual rates" - no specific definition
  - *Not* "up to" or advertised rate
  - Average rate?
  - 95th percentile rate?

- Our estimates use 95th percentile rate
  - Can be compared to minimum required for streaming playout
  - FCC texts use 95th percentile
    - National Broadband Plan, p.45
    - OBI Technical Paper No.1, p.71

Typical Capacity Requirements

- Lines combine traffic projections and NBP performance goals
- Points based on traffic projections only (5 to10 Mbps performance)

Required Downstream Capacity

2020:
2700 Mbps

2014-2020 assumes mid-range CAGR

2015:
750 Mbps

2010:
200 Mbps
50 Mbps
21 Mbps

720 Mbps

240 Mbps

320 Mbps

120 Mbps

Legend:
- 960 ports
- 960 (no NPB goal)
- 192 ports
- 192 (no NPB goal)
- 48 ports
- 48 (no NPB goal)

Y-axis: Capacity (Mbps)
X-axis: Year (2009–2020)

Access Technologies

- Each "first mile" technology analyzed against NBP goals

- Each technology has different type of limit or tradeoff
  - PON: split ratio
  - HFC: # subs vs. channels required
  - DSL: loop length
  - FWA: # subs vs. channel bandwidth vs. sectors vs. frequency …

- Growth rates used
 - Mid-range for 50 and 100 Mbps performance targets
  - Low for 4 Mbps target

- **GPON**
  - Current generation (2.5 Gbps down, 1.25 Gbps up)
    - 2020: supports >100 Mbps at 1:128 split
  - Next generation 4x capacity

- **EPON**
  - Current generation (1 Gbps down/up)
    - 2020: supports 100 Mbps up to about 1:300 split
  - Next generation 10x capacity

- **Active Ethernet**
  - Gigabit Ethernet (1 Gbps down/up)
    - 2020: dedicated connection supports 100 Mbps by definition

DOCSIS 3.0 Channels Required to meet Year 2015 FCC Performance Goal (50/20 Mbps)
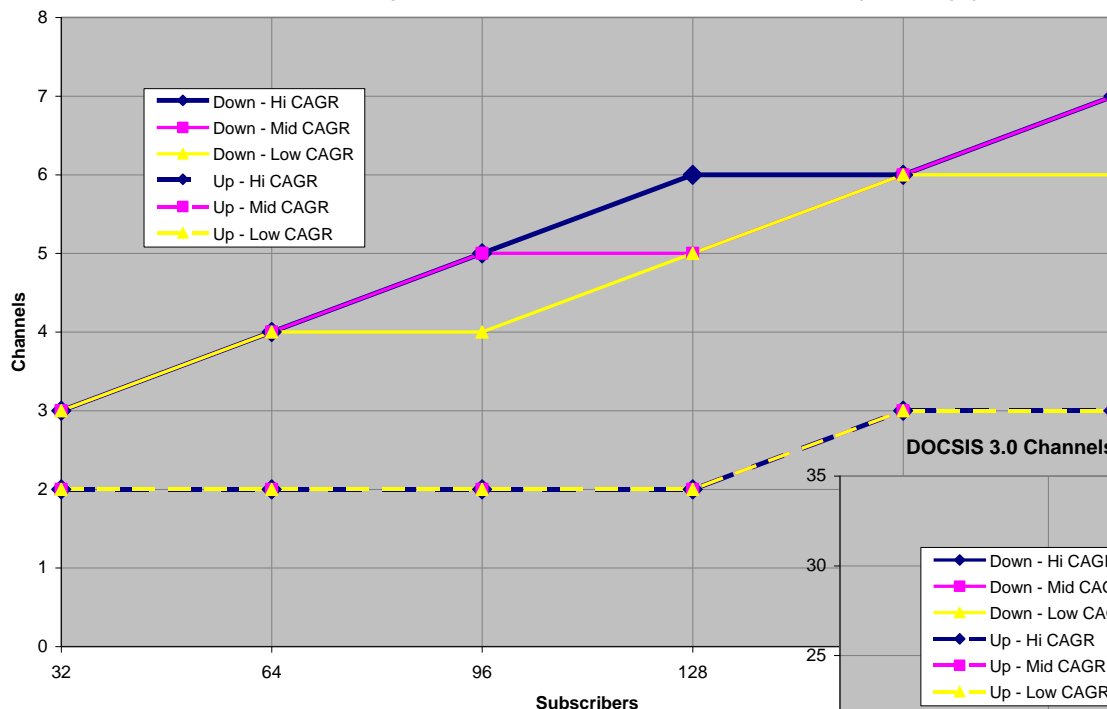
- ## Year 2015
  - 192 sub network: requires 7 channels down, 3 up

DOCSIS 3.0 Channels Required to meet Year 2020 FCC Performance Goal (100/50 Mbps)
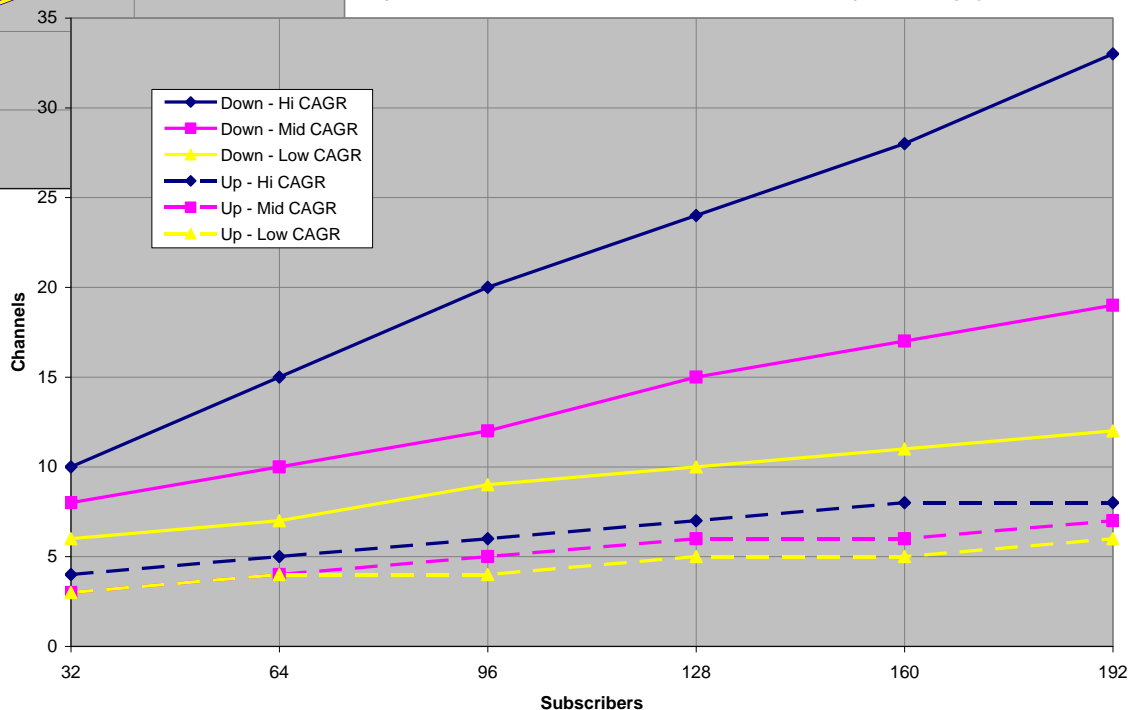
- ## Year 2020
  - 192 sub network: 19 channels down, 7 up
  - 32 sub network x6: 8 channels down, 3 up (per network)

- Dedicated connection in first mile

- Technology options
  - Conventional: performance limited by Far End Crosstalk (FEXT)
  - Vectoring: cancels FEXT
  - Pair bonding: multiplies performance by # of pairs

Loop reach in kft, 24 AWG (based on BBF 2010.029)

Year (down/up rate)	12 FEXT	Vectored	2 pair + vectored
2015 (50/20 Mbps)	1.5 kft	2.5 kft	2.9 kft
2020 (100/50 Mbps)	NA	1.3 kft	2.2 kft

- With vectoring, upstream goals limit reach
  - NBP goals vs. consumer trends
    - NBP goals trending towards symmetric rates
    - Consumer demand trending away from symmetric
  - Modified upstream requirements
    - 10 Mbps in 2015, 30 Mbps in 2020
    - Balanced down/up performance for given loop reach
    - Upstream supports multiple high quality video conferences
    - Significantly greater loop reach (2 pair + vectored)

Loop reach in kft, 24 AWG (based on BBF 2010.029)

Year (down/up rate)	Vectored	2 pair + vectored
2015 (50/20 Mbps)	2.5 kft	2.9 kft
2015 (50/10 Mbps)	2.7 kft	4.5 kft
2020 (100/50 Mbps)	1.3 kft	2.2 kft
2020 (100/30 Mbps)	1.4 kft	2.7 kft

- Performance dependent on many factors
  - Channel bandwidth and frequency
  - Distance from base station
  - Terrain and obstacles
  - Signal processing (MIMO, beamforming, spatial diversity, …)
  - Scheduling algorithm
- Analysis
  - Limit analysis to user population, channel bandwidth, average spectral efficiency
  - Ignore propagation effects (assume cell is capacity limited, not range limited)
  - Ignore cell edge spectral efficiency, use average (optimistic for fixed users near edge)
  - Parameters
    - 2:1 mobile/fixed user ratio
    - 3 sectors/cell, FDD
    - 1.3 bits/Hz directional antenna boost for fixed users
    - Low traffic CAGR for 4 Mbps target
    - Mid-range traffic CAGR for 50 and 100 Mbps targets

- ## Current generation LTE (through 2015)
  - Downstream spectral efficiency
    - 1.73 bits/Hz (mobile)
    - 3.03 bits/Hz (fixed)
  - 50 or 100 Mbps targets not feasible
  - At 4 Mbps, supports about 66 fixed users per cell in paired 10 MHz channels

- ## Next generation LTE-Advanced (in 2020)
  - Downstream spectral efficiency
    - 3.22 bits/Hz (mobile)
    - 4.52 bits/Hz (fixed)
  - At 100 Mbps: supports about 120 fixed users per cell with 80 MHz aggregated downstream bandwidth
  - At 50 Mbps: supports about 190 fixed users per cell with 80 MHz aggregated downstream bandwidth

OBI Technical Model

ADTRAN

- Good overview of technical model
  - Sound model in most respects
  - ADTRAN review focus on technology (not economics)

- Reasonably transparent

- ADTRAN references and simulation results (e.g., Exhibit 4-BT)

- Issues with technical model
  - Busy Hour Offered Load (BHOL)
  - Cell capacity estimation
  - Channel bandwidth assumptions

- Mean BHOL in 3-5 Mbps service tier
  - ☑ Year 2009: 92 to 111 kbps (ok)
  - ☑ Year 2015: 370 to 444 kbps (low but ok)
  - ☒ Year 2015: "Omitting the heaviest 10% of users" → 160 kbps (wrong)

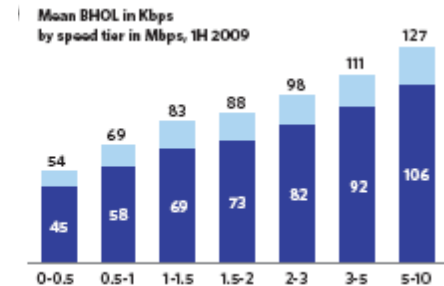- **Dimensioning BHOL at less than 40% of actual level introduces bias throughout the model**
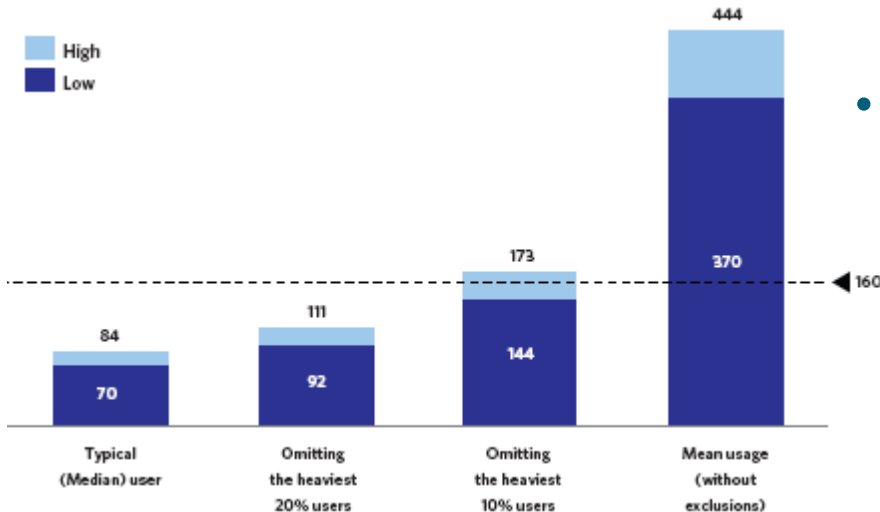

Exhibit 4-BQ (detail)

Exhibit 4-BS

- "Omitting the heaviest 10%" is *not* universal service!

- If the heaviest 10% is ideally "managed" (not omitted)
  - Large impulse at top end of demand distribution
  - Average >> 160 kbps
  - Impulse limits performance (vs. mean)
  - Ideal management not possible

- No support data or references

Exhibit 4-Q: Maximum Number of Subscribers Per Cell Site in an FWA Network with Directional Antennas at the CPE
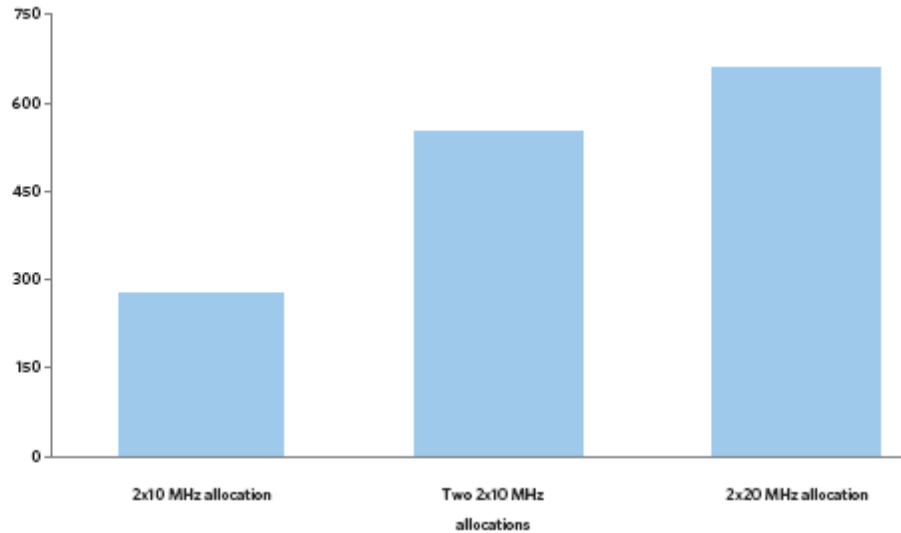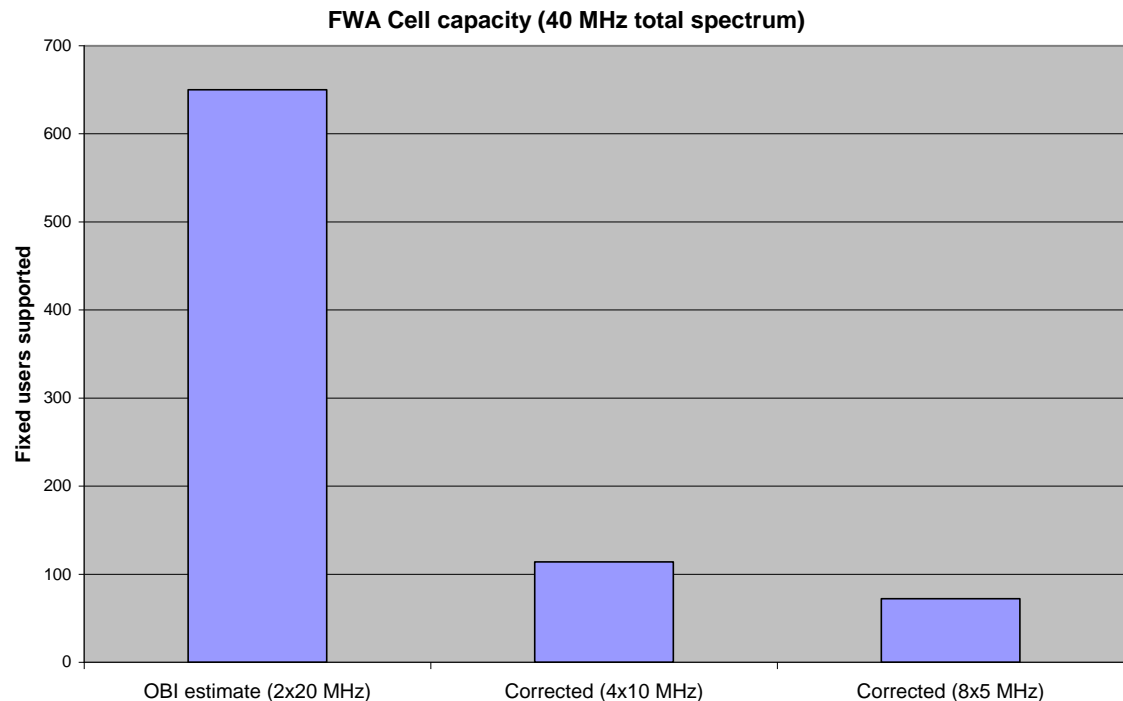
- Maximum cell capacity (2x20 MHz) estimated at 650 fixed users

- 650 fixed users → 113% average utilization
  - 160 kbps BHOL (p. 111)
  - 2 mobile users for each fixed user (pp. 53-54)
  - Fixed users generate 73% of total traffic (p. 54)
  - Avg. spectral efficiency = 1.43 for mobile users, 2.5 for fixed users with directional antennas (Exhibit 4-E and p. 72)

- Corrected cell capacity (accepting all parameters including 160 kbps BHOL) is approx. 400 fixed users
  - 70% average utilization

- Maximum cell capacity set at 650 fixed users
  - Assumes 2x20 MHz channels in the 700 MHz band (p.73)

- 700 MHz band auctioned in blocks of 6 to 12 MHz

- Few options for contiguous 20 MHz down
  - Blocks B, C, and unnamed block in between (734-757 MHz)
  - Blocks A, B, unnamed block, half of C (728-751 MHz)

- No options for contiguous 20 MHz up
  - Largest contiguous band is 18 MHz (698-716 MHz)

- Narrower channels are less efficient (Exhibit 4-Q)

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- Correcting for issues:
  - 10 Mhz channels
    - 57 fixed users/cell (per 20 MHz total spectrum)
    - 114 fixed users/cell (per 40 MHz total spectrum)
  - 5 MHz channels
    - 18 fixed users/cell (per 10 MHz total spectrum)
    - 72 fixed users/cell (per 40 MHz total spectrum)

Cell capacity in paper is high by factor of 6x (at least) for equivalent spectrum

FWA Cell capacity (40 MHz total spectrum)

Fixed users supported (y-axis): 0, 100, 200, 300, 400, 500, 600, 700

- OBI estimate (2x20 MHz): ~650
- Corrected (4x10 MHz): ~114
- Corrected (8x5 MHz): ~72

- OBI Technical Paper (and model) are completed projects

- Possible future applications
  - CAF support?
  - Broadband Deployment reports?
  - Other programs?

- OBI has noted insensitivity of FWA model results to input conditions, but …

- **Future use of model still requires correct parameters**
  - Large discrepancy (6x) exceeds range of sensitivity analysis
  - Localized results for funding purposes may be more sensitive
  - Avoid perception of bias